

Experimental Study of Axially Compressed Cold Formed Steel Channel Columns

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Abstract

Analysis and design of axially compressed cold formed steel channel section presented in this paper was conducted through experimental study, design based on British standards and North American Specification for the design of cold-formed steel structural members. More than 18 laboratory experiments were undertaken first on these steel channel columns under axial compression. A series of parametric studies were also carried out by varying the thickness and column length. All of these columns failed by local and distortional buckling. The test results were compared with American (AISI-2007) and British Standards (BS5950-Part5) for the design of cold-formed steel structural members. The details of these investigation and the outcomes are presented in this paper.

Keywords: Cold Formed Channel Sections, Axially Compressed Members, BS5950, Effective Width Method, Direct Strength Method.

1. Introduction

The use of Cold Formed Steel (CFS) structures have increased rapidly in recent years due to significant improvements in manufacturing technologies. CFS members are made from steel sheets and are formed to different shapes either through press-braking sheared form sheets or coils or more commonly, by rolling done at room temperature. CFS sections are typically thin-walled with a thickness ranging from 0.4 mm to 6.5 mm [1]. The most commonly used shapes of CFS member are lipped channel, Z and C shapes, hat and tubular sections.

The CFS sections offer one of the highest load capacity-to-weight ratios among the various structural components currently in the market. It also offers economy in production, transportation and handling. CFS sections with edge stiffened flanges have three types buckling specifically local

buckling, distortional buckling and Euler's buckling (flexural or flexural-torsional), generally called as global buckling [2, 3]. Local buckling is normally defined as a mode that involves deformation of some or all of the individual plate elements forming a cross section, possibly involving sympathetic deformations of adjacent plate elements. Distortional buckling involves deformations of the junctions between plate elements. Several studies have been conducted on cold formed steel buckling modes [4–11] by various authors.

2. Cold Formed Steel Design Methods

Currently, two basic design methods of CFS members, the traditional Effective Width Method (EWM) and the Direct Strength Method (DSM) are formally available. Until

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recently, the conventional EWM has been the only way to estimate the member strength for over 60 years. However, as structural shapes become more complex with additional lips and intermediate stiffeners, the accurate computation of the effective widths of individual elements of the complex shapes becomes more difficult and inaccurate. In order to overwhelm this problem, the DSM has been developed by Shafer et al. [3] and further studied by Hancock et al. [12].

2.1 The Effective Width Method

The Effective Width Method, introduced by Von Karman et al. [13] and subsequently modified by Winter [14], has been the primary design approach for the CFS members in the North American Specification for the Design of Cold-Formed Steel Structural Members (AISI) Specifications including the latest edition of AISI [15]. However, the EWM does not have sufficient procedures for predicting the distortional buckling failure. When sections become more complex and optimized, with additional edges and/or intermediate stiffeners, the computation of the effective widths become extremely complicated and time consuming.

2.2 The Direct Strength Design Method

The Direct Strength Design Method [16] is initially proposed in 1988 and has been adopted by the North American Cold-Formed Steel Specifications in 2004 as an alternative to the traditional EWM to estimate the compression and the flexural member strength, which can consider an interaction of local or distortional and overall buckling modes. This method does not require effective width calculations or iteration, but instead uses gross properties and the elastic buckling behavior of cross section to calculate section or member strength. Schafer [17] presented the first state-of-the-art review in the literature on the use of the 'The DSM of cold-Formed Steel member design'. Much work remains for the continued development of the cold-formed steel design methods, but the efforts of many research groups around the world are working continuously. Recently, Yu et al. [18] proposed a design method based on the EWM for determining the nominal distortional buckling strength of typical cold-formed steel C and Z sections. This method offers the same level of accuracy and reliability as the DSM, Ganesan et al. [19] studied on LRFD resistance factor for cold-formed steel compression members, Nguyen et al. [20] investigated on compression tests of cold-formed plain and dimpled steel columns, the results showed that the buck-

ling and ultimate strengths of dimpled columns were up to 33% and 26% greater than plain steel columns respectively. Goodarzian et al. [21] investigated on optimization using genetic algorithms was carried out and the cross section's parameters were obtained.

In this paper experimental investigation conducted a series of compression tests on industrial standard cold formed steel C sections and theoretically designed with British 5950-5 and AISI specifications.

3. Material Properties and Test Specimens

Axial compression tests were performed on C-section, the setup and the test rig of this section are shown in Figure 1(a). One low voltage displacement transducer is placed at mid of C-section flange to observe vertical deflection of C-Section. Lysaght high tensile C-Lipped channels Figure 1(b), is selected for this test, yield stress up to 550 Mpa and is designed in accordance to BS5950-5 and AISI specifications. Lysaght C-lipped channel with varies depth and thickness from 75 mm to 100 mm depth and 0.6 to 1 mm thickness.

Each specimen was cut to final length, ranging from 500 mm to 700 mm depending on the test group that the specimen belonged to. To ensure that the two supporting ends were parallel to each other and perpendicular to the loading axis, they were wire eroded normal to the loading axis. This ensured full contact between specimen and steel end plates. The column length was greater than three times the greatest flat width of the section and its length/radius of gyration in the direction of the least radius of gyration was kept to less than 50. This is done to prevent failure of the column due to column flexural buckling rather than local buckling (V.B.N20, 22-24).

Several test data of plain column specimens were used and the experimental critical buckling load was determined Figure 2. The test results were compared with the predicted values based on theoretical methods EWM and DSM. The measured cross section dimensions and material properties presented in Table 1.

4. Analytical Investigation

The theoretical compression capacity loads was obtained based on specifications BS5950-5 for EWM and AISI for DSM. The theoretical ultimate load of a section was

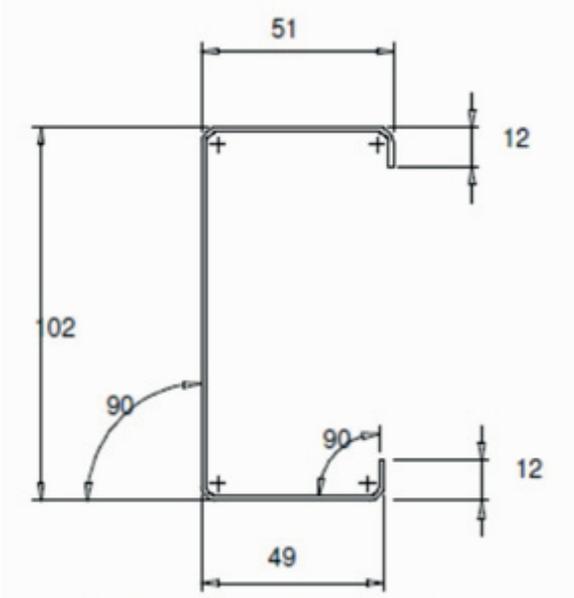


Figure 1. (a) Test Set up (b) Section dimension for C100 section.



Figure 2. Failure modes shapes.

determined from EWM described in BS5950-5, some semi-empirical formulae as follows:

The ultimate axial compression load of single symmetric composite shapes of open cross section not subject to torsional-flexural buckling determined based on Eq.(1)

$$P_c' = \frac{M_c P_c}{(M_c + P_c e_c)} \tag{1}$$

Table 1. Section dimensions and properties

Component	Thickness (mm)	Yield Stress (Mpa)	Area (mm ²)	I _{xx} x10 ⁴ (mm ⁴)	I _{yy} x10 ⁴ (mm ⁴)	Section Modulus, Z _x x10 ³ (mm ³)	Section Modulus, Z _y x10 ³ (mm ³)	Radius of Gyration R _x (mm)	Radius of Gyration R _y (mm)
C7510	1	550	137	12.2	2.85	3.25	1.02	29.84	12.67
C7512	1.2	550	204	18.9	5.2	5.14	1.84	30.43	15.96
C100	1	550	216	36.4	7.55	7.13	2.19	41.1	18.7

Where,

M_c is the moment capacity determined in accordance with section 5.2.2.

P_c is the buckling resistance under axis load determined in accordance with section 6.2.3.

e_s is the distance between the geometric neutral axis of the gross cross-section assumed as unity.

Moment capacity M_c , determined on the basis of a limiting compressive stress in the webs, p_o as per section 5.2.2.2.

$$p_o = \left\{ 1.13 - 0.0019 \frac{D_w}{t_t} \left(\frac{Y_s}{280} \right)^{\frac{1}{2}} \right\} p_y \leq p_y \quad (2)$$

where,

D_w is the section depth or twice the depth of the compression zone.

Y_s is the material yield strength in Newton per square millimeter (N/mm²)

t is the web thickness in millimeters (mm).

p_y is the design strength in Newton per square millimeter (N/mm²)

The buckling resistance under axial load, P_c , may be obtained from the following:

$$P_c = \frac{P_E P_{CS}}{\phi + \sqrt{\phi^2 - P_E P_{CS}}} \quad (3)$$

where,

$$\phi = \frac{P_{CS} + (1 + \eta) P_E}{2}$$

P_{CS} is the short strut capacity and is equal to $A_{eff} p_y$

p_y is the design strength

A_{eff} is calculated as per table 5-BS5950-5

P_E is the minimum elastic flexural buckling load and is equal to $\frac{\pi^2 E_c I}{L_E^2}$

E_c is the modulus of elasticity of composite section.

I is the second moment of area of the cross-section about the critical axis. L_E is the effective length of the member about the critical axis. η is the Perry coefficient, such that:

$$\text{for } L_E/r \leq 20, \eta = 0$$

$$\text{for } L_E/r > 20, \eta = 0.002(L_E/r - 20)$$

where,

r is the radius of gyration of the gross cross-section corresponding to P_E

$$P_u = A_{eff} P_c' \quad (4)$$

P_u is ultimate compression stress modified equation as per BS5950-5:1998 section 6.2.4

The experimental test results are also compared with capacities calculated according to AISI.

The compression capacity estimated based on AISI direct strength method.

Flexural, Torsional, or Torsional-Flexural Buckling (P_{ne})

$$P_{ne} = \begin{cases} (0.658^{\lambda_c^2}) P_y & \lambda_c \leq 1.5 \\ \left(\frac{0.877}{\lambda_c^2} \right) P_y & \lambda_c > 1.5 \end{cases} \quad (5)$$

Where,

$$\lambda_c = \sqrt{P_y / P_{cre}}$$

P_{cre} = Minimum of the critical elastic column buckling load in flexural, torsional, or torsional-flexural buckling.

Local Buckling (P_{nl})

$$P_{nl} = \begin{cases} P_{n\epsilon} & \lambda_l \leq 0.766 \\ \left[1 - 0.15 \left(\frac{P_{cr1}}{P_{n\epsilon}} \right)^{0.4} \right] \left(\frac{P_{cr1}}{P_{n\epsilon}} \right)^{0.4} P_{n\epsilon} & \lambda_l > 0.766 \end{cases} \quad (6)$$

where,

$$\lambda_l = \sqrt{P_y / P_{cr1}}$$

P_{cr1} = Criticaelastic local column buckling load.

Distortional Buckling (P_{nd})

$$P_{nd} = \begin{cases} P_y & \lambda_d \leq 0.561 \\ \left[1 - 0.25 \left(\frac{P_{crd}}{P_y} \right)^{0.6} \right] \left(\frac{P_{crd}}{P_y} \right)^{0.6} P_y & \lambda_d > 0.561 \end{cases} \quad (7)$$

where,

$$\lambda_{cd} = \sqrt{P_y / P_{crd}}$$

P_{crd} = Critical elastic distortional column buckling load.

The theoretical design loads determined from BS5950-part5 and AISI specifications were compared with the experimental ultimate loads as shown in Table 2. The

proposed ultimate capacity of cold formed steel sections based on Eq.4 and experimental results are plotted in Figure 3. A reasonable agreement is obtained. The experimental test results of the columns and the theoretical results obtained from BS5950-part5 and AISI specifications are tabulated in Table 2 and Table 3.

5. Conclusions

Axial compression tests on cold-formed lipped channel sections were conducted. A total of 27 lipped channel specimens were tested. This paper has outlined two current approaches

to the design of lipped channel sections using an extension to the DSM in AISI and EWM in BS5950-5 specifications as well as the test results. The DSM employs gross cross sectional area while EWM follows effective plate width for calculating cross section capacity. The experimental test results are very close to DSM and EWM methods.

6. References

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Table 2. Axial Compression tests results : Experimental Vs BS5950-Part5 Theoretical

Section	FY Mpa	Ultimate Axial Compression Capacity-Experimental-kN	Ultimate Axial Compression Capacity - Theoretical -kN
C7510×500mm	550	57.97	51.98
C7510×600mm	550	57.88	51.82
C7510×700mm	550	56.75	51.27
C7512×500mm	550	72.65	66.75
C7512×600mm	550	71.08	66.51
C7512×700mm	550	69.5	65.80
C10010×500mm	550	68.5	59.98
C10010×600mm	550	67.9	59.86
C10010×700mm	550	66.9	59.72

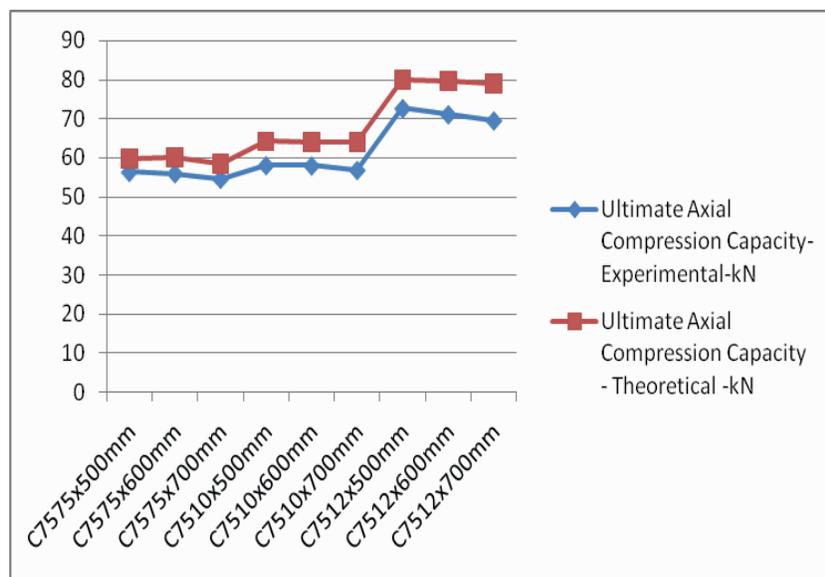


Figure 3. Graph Ultimate load - Experimental Vs Theoretical

Table 3. Axial Compression tests results: Experimental Vs AISI Theoretical

Section	FY Mpa	Ultimate Axial Compression Capacity-Experimental-kN	Ultimate Axial Compression Capacity - Theoretical -kN
C7510×500mm	550	57.97	56.56
C7510×600mm	550	57.88	55.84
C7510×700mm	550	56.75	55.00
C7512×500mm	550	72.65	84.31
C7512×600mm	550	71.08	83.28
C7512×700mm	550	69.5	82.08
C10010×500mm	550	68.5	66.40
C10010×600mm	550	67.9	66.07
C10010×700mm	550	66.9	70.08

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